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Crewed Mars Mission Concepts

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From the Agency's inception, a long-term goal of NASA has been to enable humans to explore Mars. But achieving this goal has been impeded by the reality that traveling to Mars will be extremely challenging from a technological perspective and will include significant risk to the crew. The propulsive demands are immense, and exposure to both the microgravity and radiation environments of space impacts the health of the astronauts. The orbital mechanics for a trip to Mars necessitates a round trip time of two to three years, two or more times the longest in-space experience of an astronaut to date. Past mission studies have often evaluated the longer "conjunction class" missions (approaching three years) which, while increasing mission risk due to duration, require significantly less total impulse and are therefore more feasible from a propulsive perspective.

NASA recently conducted a mission concept study to evaluate the feasibility and propulsion technology development requirements for reduced travel duration "opposition class" crewed missions to Mars. A high-level goal of the study was to minimize the mission risk and health impact on the crew caused by the space environment. This was implemented in the study by limiting the crew to a total of approximately two years of in-space operations and travel time. For the initial mission, the crew would stay about 30 days on the Martian surface. The study selected two advanced propulsion options to evaluate, each with the potential to meet the mission requirements. Both options rely on nuclear fission to provide efficient propulsive energy and both concepts rely on storing large amounts of cryogenic propellant (either LO_2/LCH_4 or LH_2) for multiple years in space without loss, transferring propellants between tanks in space, and managing the propellant in microgravity. These operations far exceeding state-of-the-art in-space cryogenic fluid management (CFM) capabilities. To enable these new capabilities, the team assumed the use of several advanced cryogenic fluid management (CFM) technologies (summarized below) and analyzed the integrated system performance. This included considering the vehicle-level impacts of the size, mass, and power requirements of including these CFM technologies. Further, the team evaluated the CFM technology development required to enable such a mission in the mid-2030s and determined that it was feasible.

Both of the concept vehicles studied are very large, on the order of the length of the International Space Station and require multiple launch vehicles to deliver the elements and propellant into Earth orbit where they are assembled. The aggregation and assembly will increase the duration the cryogens must be stored without loss and will require automated fluid couplers and propellant transfer.

One propulsion option studied was a hybrid with both nuclear electric propulsion (NEP) and chemical propulsion ("NEP/chem hybrid"). This hybrid concept had a reactor and energy conversion system powering xenon propellant ion thrusters (electric propulsion) to provide a highly efficient, but lower-thrust, push for most of the mission duration. This concept also relied on a large liquid oxygen/liquid methane (LO_2/LCH_4) chemical propulsion stage to provide high thrust for maneuvers while near the Earth and Mars, to minimize so-called "gravity well" losses. This concept vehicle is shown in Figure 1. At the far left is the nuclear reactor and energy conversion system generating 1.9 megawatts of electric power. A deployable boom provides separation between the reactor and the rest of the NEP module, and two clusters of ion thrusters are deployed from the primary axis on smaller booms. Because the energy conversion process has inefficiencies, large deployable radiators (purple in the figure) are also needed. The final piece of the NEP element is the xenon propellant stored at supercritical pressure in

several tanks along the axis of the vehicle. A large cylindrical habitat element provides for the needs of the crew. Finally, on the right end of the vehicle in figure 1 is the chemical propulsion stage, also launched separately and partially fueled to maximize tank volume within the launch vehicle. This stage is then filled in orbit by tankers and carries approximately 200 tons of LO_2/LCH_4.

The second propulsion option was nuclear thermal propulsion (NTP), in which the reactor heats liquid hydrogen (LH_2) propellant which then expands through a nozzle for thrust at about twice the efficiency of the best chemical propulsion systems. The NTP vehicle requires significant amounts of hydrogen, and due to the low density of LH_2, many tanks will be required to hold it, as seen in figure 2. The NTP vehicle includes three reactors, each integrated with turbomachinery and a nozzle into a rocket engine, at the far left of the rendering. The two largest LH2 tanks (the in-line core stage and in-line core tank) are a bronze color, and then a number of silver drop tanks are visible. As their name indicates, drop tanks are disposed of as the LH_2 is consumed to reduce vehicle dry mass for subsequent maneuvers. For the NTP concept, the same large cylindrical habitat is located at the end of the vehicle.

As noted previously, advanced CFM technologies were necessarily assumed to enable the zero-loss storage, microgravity handling, and in-space transfer of propellants required for this mission. CFM technology assumptions for the LO_2/LCH_4 tanks and LH_2 tanks were similar with a few noted exceptions. These technologies included zero-g thermodynamic venting for limited mission operations where venting may be required, surface tension-based propellant management devices, and zero-g propellant gauging. Of course, the thermal control strategy will be critical to the success of the mission. Figure 3 shows a conceptual stack-up of the insulation and active cooling layers to achieve zero boil-off storage. Spray-on foam insulation (SOFI) was assumed on the tank wall to protect against freezing of moisture or air during launch operations. For the hydrogen tanks, two-stage active cooling was analyzed. This included 20 K broad area cooling (BAC) at the wall with a 90 K BAC shield in the insulation. As these propellant tanks must survive long periods in space, including in Earth orbit during assembly, it will be necessary to include Micrometeoroid and Orbital Debris (MMOD) protection layers. To support the MMOD layers and the BAC, the team assumed the used of load-bearing multilayer insulation (LB-MLI) developed through the NASA Small Business Innovative Research (SBIR) program. The insulation for LO2 and LCH4 tanks was similar to the approach shown in Figure 3 for the LH2 tanks, except the 20 K BAC shield and inner 10 layers of LB-MLI were not necessary. The cooling for the BAC system was assumed to be provided by spaceflight reverse turbo-Brayton (RTB) coolers currently in development with NASA funding. The 20 K cooler was assumed to provide 20 W of lift and the 90 K cooler was assumed to provide 169 W of lift.

The study demonstrated, that with the advanced CFM assumptions noted above, a propellant storage and supply system that met the mission requirements was possible. A final question was whether these CFM technologies could be ready for a mission in the targeted timeframe. NASA is currently investing in maturing most of the needed CFM technologies. This includes Tipping Point Flight Demonstration Missions, led by the NASA Space Technology Mission Directorate, to prove various CFM technologies are ready for in-space application. The study team determined that by continuing these investments, along with addressing a few remaining gaps, the CFM technologies needed can be ready to enable a crewed Mars mission in the mid-2030s.

Excerpted from: "Recent Concept Study for Cryogenic Fluid Management to Support Opposition Class Crewed Missions to Mars," Michael L. Meyer, Jason W. Hartwig, Steven G. Sutherlin, Anthony J. Colozza, presented at the Space Cryogenics Workshop, November 2021 and to be submitted to Cryogenics.

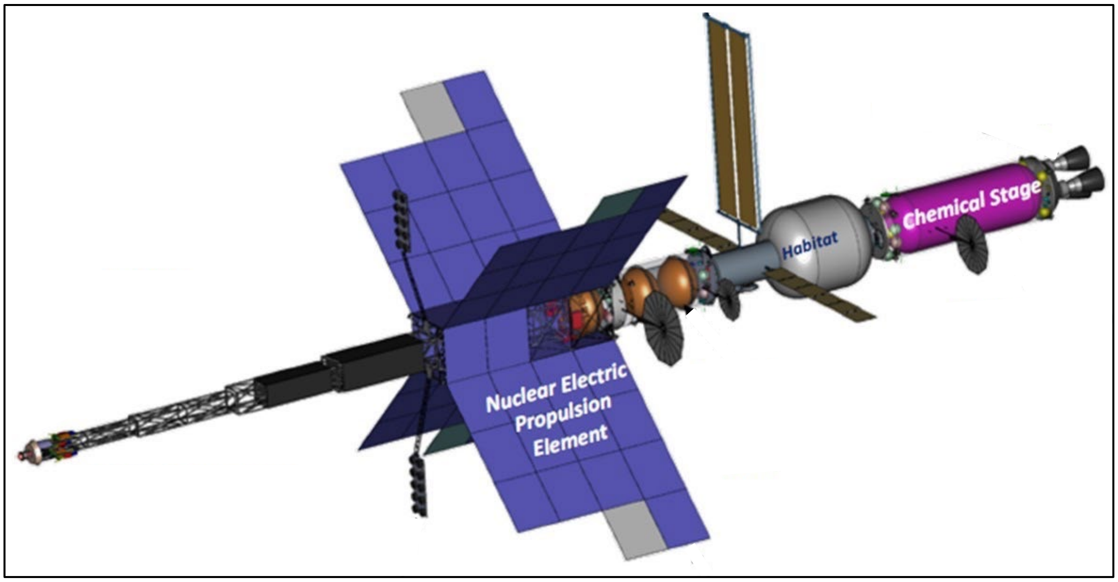

Figure 1. NEP/Chem Hybrid Propulsion Mars Transportation Vehicle Concept

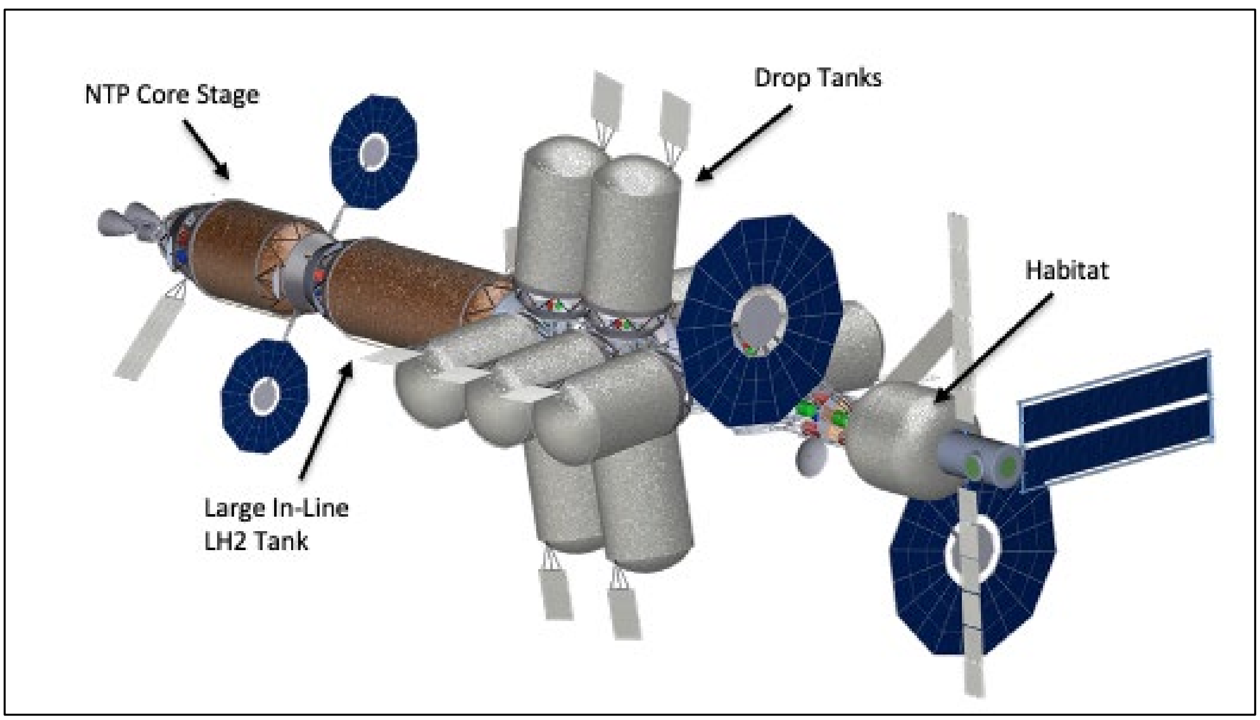

Figure 2. NTP Mars Transportation Vehicle Concept

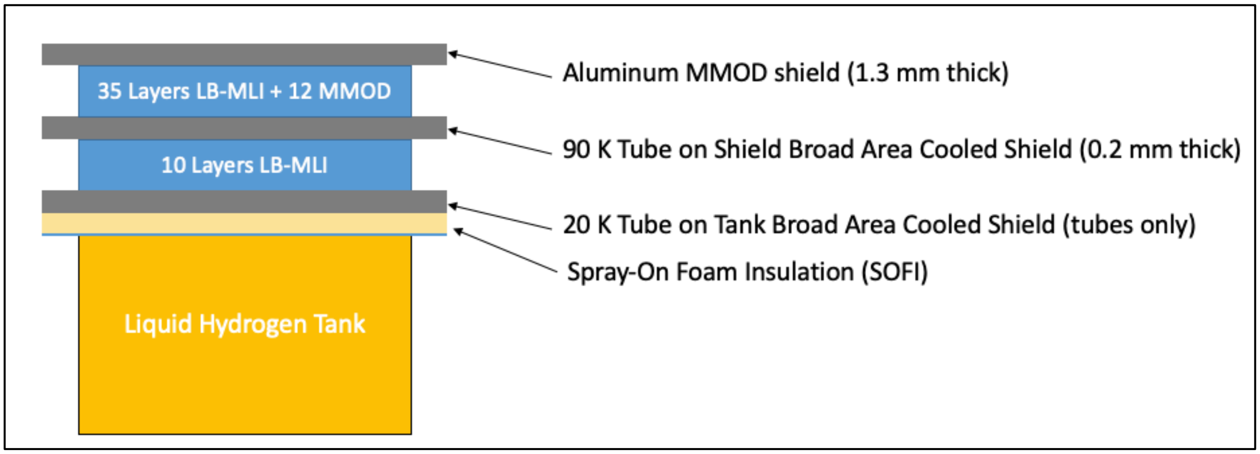

Figure 3. Insulation and Integrated MMOD Protection for LH_2 Tanks